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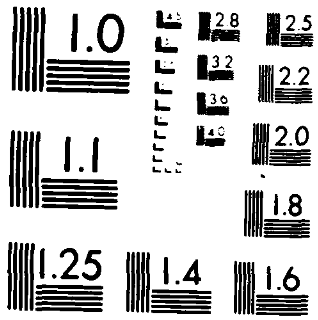

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FINAL
REPORT

Edward M. Connelly

ACCURACY AND
COMPLETENESS
OF PROBLEM
SOLUTIONS WITH
EXAMPLE
SOLUTIONS

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This research investigated the ability of computer users, both programmers and non-programmers, to specify problem solutions in the form of example-solutions. This ability was evaluated as a function of the complexity of the processor, i.e. the degree of generalization of the user inputs, the complexity of the problem, and the complexity of the feedback-aids. The experimental task employed in this study required

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the specification of a logic for the formation of a naval task-force. The performance both of programmers and non-programmers decreased with increasing levels of problem-complexity and with reduced processor support. For both the groups, errors-of-commission were relatively infrequent compared to errors-of-omission. It was found that the degree of processor-complexity was much more influential than problem-complexity in predicting performance scores. When computer generalization of user-input was provided, performance was significantly lower than during all other experimental conditions. Results also showed that participant-strategy in the generation of problem solutions was a significant factor in performance, though years-of-experience and years-of-education were not found to be good predictors of performance. The feedback-aids were shown to be most effective when they included the logic implied by the example-solutions. These experiments demonstrate the effectiveness of the on-line use of computer software to create and modify software routines.

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ABSTRACT

This research investigated the ability of computer users, both programmers and non-programmers, to specify problem solutions in the form of example-solutions. This ability was evaluated as a function of the complexity of the processor, i.e. the degree of generalization of the user inputs, the complexity of the problem, and the complexity of the feedback-aids. The experimental task employed in this study required the specification of a logic for the formation of a naval task-force. The performance both of programmers and non-programmers decreased with increasing levels of problem-complexity and with reduced processor-support. For both the groups, errors-of-commission were relatively infrequent compared to errors-of-omission. It was found that the degree of processor-complexity was much more influential than problem-complexity in predicting performance scores. When little computer generalization of user-input was provided, performance was significantly lower than during all other experimental conditions. Results also showed that participant-strategy in the generation of problem solutions was a significant factor in performance, though years-of-experience and years-of-education were not found to be good predictors of performance. The feedback-aids were shown to be most effective when they included the logic implied by the example-solutions. These experiments demonstrate the effectiveness of the on-line use of computer software to create and modify software routines.

INTRODUCTION

This is the final report on Contract N00014-79-C-0739, Work Unit Number N[illegible]-101 between Performance Measurement Associates, Inc. and the Engineering Psychology Group, Office of Naval Research. The contract was initiated on 1 Sept 1979 and ended on [illegible] 1982.

The research investigated the capability of programmers and non-programmers to specify problem solutions by developing example-solutions and also by writing computer programs; each method of specification was accomplished at various levels of problem-complexity. The level of difficulty of each problem was reflected by the number of steps needed by the user to develop a solution. Machine processing of the user-inputs permitted inferences to be developed about the algorithms required to solve a particular problem. The iterative feedback of processing results led users to a more precise definition of the desired solution.

Six experiments were conducted, with the same problems used in all experiments. The ability of the participants to develop example-solutions was evaluated as a function of the participants' background and experience, the complexity of the problem to be solved, the level of processing provided by the computer, and the level of feedback-aids, when aids were available.

Two technical reports were published and three papers were presented documenting the experiments and results obtained. These documents are identified in the list of technical reports [illegible] at the end of this report.

Experiments 1 and 2 were designed to investigate the ability of expert programmers and of bookkeepers/accountants who were not expert programmers to develop example-solutions for a hypothetical Navy task-force problem. The experimental variables for both experiments were problem-complexity and processing complexity, i.e. the amount of machine processing of [illegible].

Experiments 3 and 4 were designed to investigate the ability of expert programmers and non-programmers to develop accurate and complete example-solutions using various feedback-

aids at various levels of problem-complexity. The four [illegible] designs were based on the results of Experiment [illegible], when the systematic generation of example-solutions, [illegible] a combinational-measure, had been shown to [illegible] correlated with performance (explaining 60% of [illegible] variance).

Experiment 5 was designed [illegible] of expert programmers to revise [illegible] the form of example-solutions [illegible] incorrect entries had been introduced, [illegible] in Experiments 3 and 4.

Finally, Experiment 6 [illegible] to develop computer code written in [illegible] levels of data input – a design [illegible] design of Experiment 1. The results [illegible] sub-routines written in FORTRAN IV [illegible] a ship combination, as that combination [illegible].

The performance measures used in [illegible] consisted of error-measures and strategies-measures. [illegible] error-measures were:

a. P_T, the probability that a given ship-combination was correctly classified as acceptable or unacceptable.

b. P_C, the probability that a correct [illegible] combination was accepted.

c. P_{IC}, the probability that an incorrect ship-combination was rejected.

In addition to the error-measures above, relative error-measures were used. A relative error-measure was defined as a participant's error-score (P_T, P_C, P_{IC}) on an experimental problem minus his/her error-score on the pre-test problem. The relative error-measures thus tended to remove the effect of the participant's innate capability, and, as a result, were more sensitive to experiment factors than were the error-measures alone.

Two strategy-measures were used to detect the frequency with which participants used specific strategies. One strategy-measure, the combinational-measure, detected the frequency with which a participant changed only one component at a time of [illegible] example-solution. Another strategy-measure, the sequence-measure, detected the use-patterns of the various feedback-aids.

RESULTS OF EXPERIMENTS

Experiments 1 and 2

The results of Experiments 1 and 2, [illegible] categories, are described below. The design of Experiments 3 through 6 was largely based on them.

Processor Complexity and [illegible]

First, as expected, more errors occurred [illegible] work on the more complex problems. However, the level of processing, or generalization, of the example-solutions was found to be an important error-reducing factor, i.e., a significant reduction in errors occurred when data from example-solutions were processed into a standard form and presented to the participant.

Systematic Strategies and Feedback-Aids

A second result, and perhaps the most important, was that participants in both categories who performed well tended to use a systematic, step-by-step strategy in selecting example-solutions. This result, together with the first, noted above, suggested that feedback-aids might be designed to encourage participants to use systematic strategies, by processing their example-solutions and then feeding back the resultant data to suggest possible additional inputs.

Breadth vs. Depth of Experience

A third result of the first two experiments applied to the subsequent experiments was that the number of years of advanced education (i.e., beyond high school) and the number of years

of professional experience were found to be unimportant [illegible] in predicting performance. As a consequence of [illegible], additional demographic factors were evaluated for the [illegible] in the subsequent experiments, in an effort to reveal [illegible] predictors of performance.

Low Frequency of Errors-of-Comm[illegible]

The fourth result applied to [illegible] was the observation that only a few errors-of-comm[illegible] during the generation of the example-[illegible]. [illegible] errors that did occur were errors-of-[illegible]. [illegible] result influenced the design of Experi[illegible], [illegible] code was written to solve the same [illegible] 1, so that a comparison of error-[illegible].

Experiment [illegible]

Feedback-Aids

Three aids were developed. Aid #1 provided the [illegible] selection logic (SSL) implied by the participant's example-solutions. Aid #2 included the SSL and an ordered listing [illegible]-type of the example-solutions input by the participant. The ordered listing was intended to aid the participant by showing possible omissions in ship-combinations. Aid #3 included the SSL and a list of suggested ship-combinations to consider. The suggested ship-combinations were those logically required to complete the combinations suggested by the example-solutions previously entered.

The effect of the feedback-aids as measured by the error-score (P_C), i.e. by the probability of accepting a correct ship-combination, was not statistically significant. However, the effect of the aids as measured by the relative error-score (error-score on the experiment problem minus the error-score on the pretest problem) was found to be significant and important. Apparently, the feedback-aids did help at least a portion of the participant population -- the less-than-superior performers. Those who would perform well without the aids were not helped by the aids. Also, it was apparent that variations in performance due to the participants' innate abilities were greater than variations in performance due to the feedback-aids. This factor,

plus the observation that superior performers may not need or use the aids, may account for the insignificant effect of the aids on error-score and the significant effect on relative-[illegible]-score.

Feedback-Aid #6 appeared to affect performance to a greater degree than Aid #2. Aid #6 included recommendations of logical example-solutions based on [illegible] example-solutions input previously. Aid #2, on the other hand, included an ordered list of example-solutions previously [illegible]. With Aid #2, the participant had to examine the pattern of previous inputs and identify any missing example-solutions. With Aid #6, the participant was presented with recommendations. [illegible] example-solutions previously [illegible] not in error, [illegible] reasonable to expect that Aid #6 might support performance [illegible] than that supported by Aid #2.

Aid #3 could give false recommendations, however, without indicating the basis for these recommendations. If, for instance, Aid #6 was used early in the problem, when only a few example-solutions had been input by the participant, there were possible next-logical patterns which were not correct. Also, when the participant inputed an example-solution that contained an error, Aid #6 would recommend solutions that actually completed the error-induced patterns. Such aids as Aid #6 can thus be either helpful or harmful, depending on how they are used. When recommended solutions are used without careful evaluation, this type of feedback-aid is potentially harmful. If, however, the display of patterns built upon an error increases the likelihood of the error's detection - by displaying its impact - then aids that provide recommended solutions may help the user to detect input errors.

Breadth vs. Depth of Experience

The lack of a strong predictive relationship between years-of-higher-education or years-of-experience and performance may come as a surprise to educators and directors of personnel departments. This result was found in all of the experiments, so that very strong evidence is available to support the assertion that years-of-education and relevant work-experience are not good predictors of problem-solving performance.

Additional results suggest that the "number of programming languages (used on 1 or more programs)" and "number of operating systems used" are better predictors of the [illegible] of computer users/programmers.

Combinational Strategy

Combinational-strategy was [illegible] predictor of performance. [illegible] Experiments 1 and 2, where approximately the [illegible] variance was explained by combinational-strategy [illegible] Experiments 1 and 2 and [illegible] in Experiments [illegible] and 4). [illegible] the combinational-[illegible] to-moment measure [illegible] operational-[illegible]. A moment-to-moment measure [illegible] lated to performance and thus provided greatly improved [illegible] sensitivity.

Experiment 5

Feedback-Aids

In Experiment 5, participants were asked to [illegible] example-solutions that included various numbers of [illegible] combinations. This experiment design permitted calculation [illegible] the probability of maintaining an initially-correct example-[illegible] and the probability of detecting and correcting an initially-[illegible] example-solution.

Analyses of grand-mean probabilities of success [illegible] that the probability of maintaining an initially-correct solution was .93. However, there was a probability of .65 for detecting and correcting an erroneous example-solution. Obviously, there was a performance decrement in the detection and correction of erroneous example-solutions. Useful feedback -aids might thus be directed toward the detection and correction of existing errors.

Feedback-Aids #2 and #3, which were the same as those used in Experiments 3 and 4, were not, however, a benefit to participants engaged in the revision of example-solutions. Further, an analysis using relative measures, which tended to remove the effect of participant skill, did not result in statistically significant results. The conclusion, then, was that the strategies used

successfully to revise existing solutions. Results, however, [illegible] that the aids designed to help in the development of new solutions were not helpful in revising incorrect problem-solutions.

Relativity of Error Detection

But there appears to have been a more [illegible] in detection of errors. As the number of incorrect example-solutions was decreased, there was a decrease in the [illegible] detecting and correcting these incorrect example-solutions. The fewer the number of errors, the lower was the probability of detecting a given error.

This result suggests that there may be a base-line probability (based on the frequency of errors recently detected) of detecting and correcting errors which affects the probability of judging that any solution is incorrect. Thus, the "correctness" of a solution as determined by a user may be a function of:

1. The actual correctness of that solution,

2. The perceived frequency of erroneous solutions found recently.

This hypothesis, consistent with predictions of signal detection theory (which says that the probability of an event is a function of a base-line probability in addition to specific measurements on the signal itself), predicts a decreasing probability of detecting and correcting errors with decreasing error-rates. This means that the probability of detecting the last few errors may be so small that it is not likely that they will be found. But it also suggests a possible solution: seeding errors (which can later be removed if not detected) to increase the base-line error rate and, thus, to increase the probability of detecting unknown errors.

Experiment 6

Two types of errors were analyzed. One type, termed an "error-of-omission", referred to an error that resulted in a failure to accept a correct entity (e.g.ship combination). When specifying a problem solution with example-solutions, an error-

of-omission could be [illegible] to enter [illegible] of a suitable entity ([illegible]). [illegible] second type of error considered was an "error-of-[illegible]." [illegible] example-solutions were used to [illegible], an error-of-commission corresponded to [illegible] processor which was [illegible] example. An error-of-[illegible] accepting incorrect [illegible].

<u>Errors-of-Omission</u>

There was [illegible] complexity on error-of-[illegible] of specifying problem [illegible], i.e., [illegible] FORTRAN IV subroutine[illegible].

<u>Errors-of-Commission</u>

When [illegible] example-[illegible] aids, the rate of error-of-com[illegible] problem complexity-[illegible] Halstead's E Metric.* But, given [illegible], such as in Experiment 3, [illegible] could be eliminated, as evidenced [illegible] which performance degradation [illegible].

The most important [illegible] errors-of-commission was that specification by example-solution was [illegible] to specification by program code. Analysis of the mean [illegible] from Experiments 1, 2, and 3 provided [illegible] evidence [illegible] example-solutions substantially reduced errors-of-commission compared to using FORTRAN IV program code. The 3% rate for errors-of-commission with example-solutions compared favorably with 18% for program code.

Three hypotheses concerning the superior performance of the example-solution method seem plausible:

1. It was working with examples and dealing with each individual combination of items one-at-a time that resulted in a low rate of errors-of-commission.

*For a discussion of Halstead's E Metric, See Connelly, Comeau & Johnson, Technical Report 81-361, 1981.

2. It was the specification of each solution one-at-a-time that alone was [illegible]. In other words, if computer programs were developed [illegible] each solution combination one-at-a-time, the rate of errors-of-commission would [illegible].

3. The [illegible] of the example-solution [illegible] was due, in part, to the [illegible] of example-solutions from one [illegible] into another form, [illegible] different form, [illegible], it was [illegible] that [illegible] the user to view [illegible] way and that resulted in a low [illegible] errors-of-commission. Consequently, if [illegible] by the user were transformed into a different logic form and fed back to the user for approval, a low rate of errors-of-commission would be obtained.

These hypotheses are not alternative hypotheses – all could be true. We have strong evidence that the first hypothesis is true. If the second is true but not the third, program-design and coding methods could be adapted to a more combination-dependent structure. And finally, if the third hypothesis were found to be true, pre-compilation [illegible] the user's program code into another form (while maintaining the same program logic) for feedback to the user.

CONCLUSIONS

1. Feedback-aids, to support use of example-solutions, should include the logic implied by the example-solutions as well as new example-solutions that complete the logic patterns suggested by the existing set of example-solutions.

2. Feedback-aids consisting of an ordered listing of all present solutions also supported high performance; but, the predictive aid type referred to above is preferred.

3. Feedback-aids assisted [illegible] the performance of both programmers and non-programmers who did not perform well without [illegible].

4. Performance measures designed to detect feedback performance improvement with feedback-aids should be relative measures, which indicate the difference between performance on a common task and on an experimental task.

5. The lack of a strong relationship between "years-of-higher-education", "years-of-experience" and performance, coupled with the strong relationship between "number of computer languages" known and "number of operating systems" used, suggests that education and experience should not be used as they have been in the past for hiring, promotion, determining salary level, and assigning tasks. Instead, the number of computer languages known and the number of operating systems used, which are better performance predictors, should be used until the underlying factors [illegible] are discovered.

6. Apparently, the depth of an individual's experience is not as important to performance as is the breadth of his experience.

7. A possible common underlying experience-related factor is the ability to view problems from alternative viewpoints, or the ability to develop alternative approaches to problems – an ability that might be enhanced with feedback-aids.

8. The performance-prediction capability of strategy-measures, developed as moment-to-moment measures, not only clearly demonstrates that systematic strategies were used by successful participants (which led to the design of the feedback aids), but also convincingly demonstrates that moment-to-moment measures provide the sensitivity to explain considerable performance variance (approximately 60% in Experiments 1 thru 4).

9. When modifying initially-incorrect example-solutions, the probability (.96) of maintaining an initially-correct example-solution was approximately the same as the probability of developing a new correct example-solution. Also, the mean probability of detecting and correcting an erroneous example-solution was low (.[illegible]). It is suggested that new aids should be developed to [illegible] in the detection and correction of existing errors.

10. The probability of detecting and correcting an erroneous example-solution decreased as the initial number of erroneous example-solutions was decreased. The fewer the total number of errors the less was the likelihood of detecting a given error. This suggests that a method for increasing the probability of detecting errors is to seed errors, unknown to the individual reviewing the example-solutions (or computer program) but otherwise recorded, to increase the base-line rate of error detection and therefore to increase the probability of detecting an unknown error.

11. Software error-categories are typically defined only to facilitate data collection and recording. However, analysis of software errors showed that when an error category was decomposed into sub-categories the independent variables in the prediction equations changed. It is concluded, therefore, that software error-categories should be selected with regard to predictability as well as to data collectability. Two sub-categories should be combined only when their prediction equations are homologous, i.e. have the same independent variables.

12. The superior performance (fewer errors-of-commission) achieved when using example-solutions and inductive processing to specify problem solutions over the performance achieved when using FORTRAN IV code may provide a basis for determining the underlying mechanism for that success and a means for incorporating that

mechanism into program-design- and coding-aids. Apparently, superior performance was [illegible] either because each combination of the input variables was treated individually and/or because the example-solutions were transformed into another logic form -- the [illegible] selection logic ([illegible]). If the former is a significant factor, then [illegible] should be adapted to program-design- and coding-aids. If the latter is a significant factor then [illegible] design- and coding-aids should be developed to transform the logic provided by the user into another form which is then fed back to the user for his review. Such a transformation might present the program's equivalent logic.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. The strategy-measures used to analyze FORTRAN IV were not moment-to-moment measures. Instead, they were a classification of types of possible strategies. The predictive power of the measures was only moderate compared to those used to evaluate performance in developing example-solutions. It is suggested that moment-to-moment strategy-measures be developed for both program-design and program-code tasks.

2. Feedback-aids designed to support development of original example-solutions were not found applicable to the revision of erroneous example-solutions. Since use of example-solutions is a viable way to specify problem solutions in itself, and reveals ways of improving program design and code, successful revision-strategies should be identified, and revision-aids should be derived from those strategies.

3. The "number of programming languages" known and the "number of operating systems" used have been shown to be good predictors of performance both in developing example-solutions and in writing program code. It is also suggested that the ability to develop alternative approaches may be a common

factor which may be enhanced by learning new languages and operating systems, and which may be a key performance-factor. The underlying factor or factors resulting in superior performance should be determined to assist in personnel selection and design of improved aids.

4. It is suggested that error-detection capability may be a function of a base-line error-[illegible] rate, and therefore that seeding errors unknown to the individual checking the material may increase the probability of detecting an unseeded error. This conjecture should be subjected to experimental test to determine if seeding improves performance, and, if so, what frequency and type of seeded errors should be used.

5. The basis for superior performance with example-solutions needs to be resolved. The concept of writing program code for each combination of factors (or the use of an aid to automatically analyze logic to help develop accurate combination-independent logic) and the concept of code transformation into a different logical form for feedback to the user for approval need to be contrasted in an experimental environment. There is a potential here for substantially increasing the correctness of computer programs if an aid can be developed to permit transfer of the superior, almost error-free performance with example-solutions to code-writing performance.

6. Independent of the methods for improving performance in writing program code suggested in Recommendation 5, a new aid design should be considered that combines general statements written in program code with redundant example solutions -- i.e. with example-solutions that are not part of a program test, but, instead, that are inductively transformed into an alternative code. A pre-compiler aid would produce actual code from both sources. Potential performance-improvement could provide high-quality, almost error-free code.

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